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ENHANCING IMMUNE RESPONSES TO GENETIC IMMUNIZATION

This application claims the benefit of co-pending provisional application Serial No. 60/082,600 filed April 22, 1998, which is incorporated by reference herein.

TECHNICAL AREA OF THE INVENTION

The invention relates to the area of immune responses to genetic immunization. More particularly, the invention relates to enhancing immune responses to DNA immunogens using immune co-stimulatory molecules.

BACKGROUND OF THE INVENTION

The use of genetic immunization, or immunization with DNA encoding polypeptide immunogens, to prime immune responses is viewed as a promising vaccine strategy. This technology offers potential improvements compared to other types of vaccines, such as subunit proteins complexed with adjuvants or inactivated or attenuated viral preparations. In addition to the practical advantages of simplicity of construction and modification, injection of genetic material encoding for polypeptide immunogens results in synthesis of the immunogens in the host. Thus, these immunogens are presented to the host immune system with native post-translational modifications, structure, and conformation.

In mice, several DNA vaccines have been effective at inducing long-lived antibody and cytotoxic T lymphocyte (CTL) responses and have conferred protective immunity against a number of viruses, bacteria, parasites, and tumors (1-8). Various

approaches to enhance immune responses mediated by genetic immunization have been investigated. In addition to variations in dosage, route or boosting regimens, these variations include co-injection of polynucleotides encoding co-stimulatory molecules which improve immunogen presentation to lymphocytes, such as B7-1 or B7-2, or cytokines, such as GM-CSF, IL-2, IL-2, and IL-12, to create an optimal cytokine microenvironment for T cell priming (11-19). However, further enhancement of immune responses to genetic immunization is desirable for immunizing mammals, particularly humans, against immunogens such as virus- and tumor-specific immunogens.

Thus, there is a need in the art for methods of enhancing the immune responses to DNA immunogens.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a method of enhancing an immune response to a DNA immunogen. This and other objects of the invention are provided by one or more of the embodiments described below.

One embodiment of the invention provides an immunogenic composition. The composition comprises a DNA immunogen and a chemokine or a polynucleotide encoding a chemokine.

Another embodiment of the invention provides a method of enhancing an immune response to a DNA immunogen in a mammal. A chemokine or a first polynucleotide encoding a chemokine and a DNA immunogen are administered to the mammal. An immune response to the DNA immunogen is thereby enhanced.

The present invention thus provides the art with the information that chemokines can be used to enhance an immune response of a mammal to a DNA immunogen. The invention can be used to, *inter alia*, to immunize or vaccinate a mammal against an infectious disease or a tumor.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1. Figure 1 shows the immunization and bleeding schedules for animals immunized with HCV immunogens.

Figure 2. Figure 2 shows the immunization and bleeding schedules for animals immunized with granulocyte-macrophage colony-stimulating factor (GM-CSF).

Figure 3. Figure 3 shows the immunization and bleeding schedules for animals immunized with HCV immunogens and RANTES.

Figure 4. Figure 4 shows the immunization and bleeding schedules for animals immunized with HCV immunogens and macrophage inflammatory protein 1 α (MIP-1 α).

Figure 5. Figure 5 shows the increased anti-HIV gag antibody titer in mice immunized with a plasmid encoding HIV gag and a plasmid encoding the chemokine B lymphocyte chemokine (BLC).

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

It is a discovery of the present invention that administration of a chemokine or a polynucleotide encoding a chemokine can be used to enhance an immune response in a mammal to a DNA immunogen. This method can be used, *inter alia*, to increase immunological resistance to pathogens, such as viruses and bacteria, and to tumor-associated immunogens.

Chemokines generally function as chemoattractants for cells which they recruit from the blood to sites of infection. Thus, administration of a chemokine, either together with or in addition to a DNA immunogen, effectively recruits various cell populations, including antigen presenting cells and effector cells, to the site of administration or its vicinity. Similarly, administration of a polynucleotide encoding a chemokine can result in local chemokine secretion which induces migration of antigen presenting cells and/or lymphocytes to the site of administration and which enhances immune responses to the DNA immunogen. Local chemokine secretion can also enhance the migration of cells which have taken up the DNA immunogen or

polypeptides encoded by the DNA immunogen to the lymph nodes, where priming of specific T cells can occur.

Chemokines which can be used in the method of the invention include, but are not limited to, B lymphocyte chemokine (BLC), IL-8, PBP/ β -TG/NAP-2, macrophage inflammatory proteins MIP-1 α , MIP-1 β , and MIP-3 α , macrophage chemoattractant and activating factor (MCP-1 or MCAF), MCP-2, MCP-3, I-309, C10, HCC-1, RANTES (regulated upon activation, normal T cell expressed and secreted), lymphotactin, SCM-1, eotaxin, MGSA, PF4, NAP-2, IP-10, ENA-78, EMF-1, GCP-2, SLC, ELC, and SDF-1. Certain chemokines may be more effective in combination with a particular DNA immunogen than others at stimulating an immune response; optimization of the DNA immunogen-chemokine combination can be carried out using routine assays in standard animal models (see Examples 1 and 2).

The immune response which is enhanced can be any response which is influenced by chemokines, including, but not limited to, antibody production or cytotoxic T lymphocyte (CTL) response resulting from chemoattraction and/or activation of antigen presenting cells, such as dendritic cells, macrophages, and monocytes, chemoattraction and/or activation of neutrophils, including eosinophils, and chemoattraction and/or activation of naive T cells, memory T cells, and pre-T cells to the thymus.

Measurement of enhanced immune responses can be carried out as is known in the art. For example, antibody titer can be measured by assays such as agglutination, immunoprecipitation, or ELISA.

Assays for chemotaxis relating to neutrophils are described in Walz *et al.* (1987), *Biochem. Biophys. Res. Commun.* 149: 755; Yoshimura *et al.* (1987), *Proc. Natl. Acad. Sci. USA* 84: 9233, and Schroder *et al.* (1987), *J. Immunol.* 139: 3474. Chemotaxis of lymphocytes can be assayed as described in Larsen *et al.*, *Science* 243: 1464: (1989) and Carr *et al.*, *Proc. Natl. Acad. Sci. USA* 91: 3652 (1994).

Assays for chemotaxis of tumor-infiltrating lymphocytes are described in Liao *et al.* (1995), *J. Exp. Med.* 182: 1301; for hemopoietic progenitors, in Aiuti *et al.* (1997), *J. Exp. Med.* 185: 111; for monocytes, in Valente *et al.* (1988), *Biochem.* 27:

4162; and for natural killer cells, in Loetscher *et al.* (1996), *J. Immunol.* 156: 322, and in Allavena *et al.* (1994), *Eur. J. Immunol.* 24: 3233.

Attraction or activation of eosinophils, dendritic cells, basophils, and neutrophils, can also be measured. Assays for determining eosinophil attraction are described in Dahinden *et al.*, *J. Exp. Med.* 179: 751 (1994), Weber *et al.*, *J. Immunol.* 154: 4166 (1995), and Noso *et al.*, *Biochem. Biophys. Res. Commun.* 200: 1470 (1994). Attraction of dendritic cells can be measured as described, for example, in Sozzani *et al.*, *J. Immunol.* 155: 3292 (1995). Assays for attracting basophils are taught in Dahinden *et al.*, *J. Exp. Med.* 179: 751 (1994), Alam *et al.*, *J. Immunol.* 152: 1298 (1994), and Alam *et al.*, *J. Exp. Med.* 176: 781 (1992). Activation of neutrophils is taught in Maghazaci *et al.*, *Eur. J. Immunol.* 26: 315 (1996) and Taub *et al.*, *J. Immunol.* 155: 3877 (1995). Cytotoxic T lymphocyte assays can also be used to measure enhanced immune response to a DNA immunogen (see Example 1, below).

The DNA immunogen can be any contiguous sequence of deoxyribonucleotides encoding a polypeptide which is capable of eliciting an immune response. For example, polynucleotides encoding immunogenic polypeptides of viruses such as HIV viruses (*e.g.*, gag, pol, or env), herpes viruses (*i.e.*, HSV-1, HSV-2), Epstein-Barr virus, varicella-zoster virus, cytomegalovirus, and hepatitis B virus (HBV), hepatitis C virus (HCV), and human papilloma viruses (*i.e.*, HPV-16, -18, and -31) can serve as a DNA immunogen. DNA which encodes polypeptide immunogens of other infectious agents, such as bacteria, fungi, or yeast, can function as a DNA immunogen in the method of the invention. DNA which encodes polypeptides specifically expressed by a tumor, such as EGFRvIII, Ras, or p185^{HER2}, or polypeptides which are expressed both by a tumor and by the corresponding normal tissue, can also function as a DNA immunogen. If desired, a DNA immunogen can comprise coding sequences for more than one immunogenic polypeptide.

A chemokine and a DNA immunogen can be administered to a mammal, preferably a human, by any means known in the art, including parenteral, intranasal, or intramuscular injection, or coated onto small metal projectiles and injected using a biological ballistic gun ("gene gun"). Alternatively, a chemokine and a DNA immunogen can be administered successively. The chemokine can be administered

prior to administration of the DNA immunogen, or the DNA immunogen can be administered prior to the administration of the chemokine.

5 A polynucleotide encoding the chemokine can also be administered. Preferably, a polynucleotide encoding the chemokine and a polynucleotide comprising the DNA immunogen are co-injected. The polynucleotides can also be administered successively, in any order. For co-administration, a single polynucleotide comprising both chemokine-encoding sequences and the DNA immunogen can be administered, or the DNA immunogen and the chemokine-encoding polynucleotide can be provided separately and mixed together prior to administration.

10 The invention also provides immunogenic compositions comprising a DNA immunogen and a chemokine or a polynucleotide encoding a chemokine. The composition can optionally comprise a pharmaceutically acceptable carrier. Pharmaceutically acceptable carriers are well known to those in the art. Such carriers include, but are not limited to, large, slowly metabolized macromolecules, such as proteins, polysaccharides, polylactic acids, polyglycolic acids, polymeric amino acids, amino acid copolymers, and inactive virus particles. Pharmaceutically acceptable salts can also be used in compositions of the invention, for example, mineral salts such as hydrochlorides, hydrobromides, phosphates, or sulfates, as well as salts of organic acids such as acetates, propionates, malonates, or benzoates. Compositions of the invention can also contain liquids, such as water, saline, glycerol, and ethanol, as well as substances such as wetting agents, emulsifying agents, or pH buffering agents. Liposomes, such as those described in U.S. 5,422,120, WO 95/13796, WO 91/14445, or EP 524,968 B1, can also be used as a carrier for a composition of the invention.

20 Compositions of the invention can be used as vaccine compositions, for example, to enhance an immune response of a mammal, including a human, to an infectious agent or a tumor. The particular dosages of chemokine and DNA immunogen which are sufficient to enhance an immune response to the DNA immunogen will vary according to the chemokine and DNA immunogen being used and the mammal to which the chemokine and DNA immunogen are being administered. The amounts of each active agent in the examples described below provide general guidance for the range of each component to be utilized by the

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practitioner upon optimizing the method of the present invention for practice either *in vitro* or *in vivo*. Generally, 0.1, 0.2, 0.3, 0.4, 0.5, 0.75, 1.0, 1.5, 2.0, 2.5, or 5 mg of a chemokine protein, a polynucleotide encoding a chemokine, or a polynucleotide comprising a DNA immunogen will be administered to a large mammal, such as a baboon or a human.

Such ranges by no means preclude use of a higher or lower amount of a component, as might be warranted in a particular application. For example, the actual dose and schedule may vary depending on whether the compositions are administered in combination with other pharmaceutical compositions or depending on individual differences in pharmacokinetics, drug disposition, and metabolism.

The following are provided for exemplification purposes only and are not intended to limit the scope of the invention described in broad terms above.

EXAMPLE 1

Co-administration of HCV immunogens and MIP-1 α increases lysis of autologous B cells infected with vaccinia virus encoding HCV polypeptide NS3

HCV immunogens. Each plasmid comprises a CMV enhancer/promoter and is Kanamycin-resistant. Plasmids were prepared by an alkaline lysis method from *E. coli* bacteria and purified using Qiagen purification systems. After purification, plasmids were stored at -80 °C, at a concentration of 1 mg/ml.

Plasmid pCMVKm Δ NS comprises hepatitis C viral DNA encoding HCV polypeptides Δ NS3, NS4, NS5a, and NS5b (immunogen for animal Group 1). Plasmid NS-GM2 encodes HCV polypeptides Δ NS3, NS4, NS5b, NS5b, and hGM-CSF (immunogen for animal Group 2). Plasmid pCMVLhRantes encodes human RANTES protein. pCMVLhMIP1a encodes MIP-1 α .

For the immunization protocols described below, pCMVKm Δ NS was premixed with either pCMVLhRantes (immunogen for animal Group 3) or pCMVLhMIP1a (immunogen for animal Group 4). Each plasmid was at a concentration of 1 mg/ml of DNA, for a total of 2 mg/ml of DNA per mixed

immunogen.

Injection of HCV immunogens into baboons. On the day of injection, one vial (marked with the plasmid name and animal group) per animal was removed from the freezer, thawed at room temperature, and gently mixed. Each immunogen was injected both intramuscularly and intradermally. The total volume injected per animal was 1 ml.

The left and right tibialis anterior muscle was injected with 400 μ l of DNA for a total of 800 μ l intramuscular injection per baboon, using a 1 ml syringe. The immunogens were injected slowly, over about 10 seconds. After injection, the needle was removed slowly, to reduce leakage.

Each of two separate sites of the upper back was injected with 100 μ l of DNA for a total of 200 μ l intradermal injection per baboon, using a 0.3 ml U-100 Insulin syringe. The skin at the sites of injection was shaved. At each site, the needle was inserted the needle bevel up into the skin and then rotated 90 degrees so that the bevel pointed to the side. The 100 μ l was slowly injected over about 10 seconds. After injection, the needle was slowly rotated so that the bevel was up again, then withdrawn slowly to reduce leakage.

Immunization and bleeding schedules for four groups of baboons. Baboons in each of four groups were immunized and bled according to the following schedule. Group 1 (animals CK544, CK545, CK546, and CK547) received inoculations of pCMVKm Δ NS (HCV immunogens) and were bled according to the schedule in Figure 1. Group 2 (animals CK548, CK549, CK550, and CK551) received inoculations of NS-GM2 (HCV immunogens and GM-CSF) and were bled according to the schedule in Figure 2. Group 3 (animals CK552, CK553, CK554, and CK555) received inoculations of pCMVKm Δ NS and pCMVLhRantes (HCV immunogens and RANTES) according to the schedule in Figure 3. Group 4 (animals CK556, CK557, CK558, and CK559) received inoculations of pCMVKm Δ NS and pCMVLhMIP1a (HCV immunogens and MIP-1 α) and were bled according to the schedule in Figure 4.

Immunizations were carried out as described in Example 2, above. At each of the times indicated in the bleeding schedules, blood was drawn from the femoral vein

while the baboons were under anesthesia (Ketamine®, 10 mg/ml). Blood was treated with heparin. B and T cells were isolated from these blood samples and used in the cytotoxic T lymphocyte assays described below.

5 *CTL assays.* Autologous B cell lines from each animal were established by transforming B cells with *H. papio*. Separate samples of peripheral blood mononuclear cells were restimulated with immortalized autologous B cells infected with a recombinant vaccinia virus that encodes each of the HCV immunogens (NS3, NS4, NS5a, and NS5b). Two weeks later, CD8⁺ T lymphocytes were purified from the samples using magnetic beads.

10 The ability of T cells from each animal to lyse its autologous B cell line infected with vaccinia virus encoding the same immunogens used to immunize the animals was tested using a standard ⁵¹Cr-release assay. Ratios of effector (T cells) to target (B cells) of 40:1, 10:1, and 2:1 were tested.

15 Percent lysis was calculated in each assay. A positive CTL response was noted if at least 10% more lysis occurred with homologous cells (stimulated with a vaccinia virus encoding an HCV immunogen) than with heterologous cells (stimulated with a vaccinia virus encoding an unrelated immunogen) for each of the two highest effector to target cell ratios tested.

20 Table I shows the number of animals with positive responses in a cytotoxic T lymphocyte assay.

Table I. Number of animals with CTL responses

| Immunogen | No. of Animals |
|----------------------------|----------------|
| pCMVNS3-5 | 0/4 |
| pCMVNS3-5 & MIP-1 α | 1/4 |
| pCMVNS3-5 & RANTES | 0/4 |

25 Table II shows percent lysis of target cells from animal CK556 after

restimulation. Homologous cells were stimulated with vaccinia virus encoding HCV polypeptide NS3.

Table II. Percent lysis of targets after restimulation (animal CK556)

| | Effector:Target | Homologous ¹ | Heterologous ² |
|-------------------------------|-----------------|-------------------------|---------------------------|
| pre-immunization | 40:1 | 2 | 11 |
| pre-immunization | 10:1 | 6 | 10 |
| pre-immunization | 2:1 | 7 | 6 |
| 2 weeks post 3rd immunization | 40:1 | 27 | <1 |
| 2 weeks post 3rd immunization | 10:1 | 17 | <1 |
| 2 weeks post 3rd immunization | 2:1 | 11 | <1 |

The results reported in Table II demonstrate that co-administration of HCV immunogens and the chemokine MIP-1 α resulted in an increased lysis of autologous B cells infected with vaccinia virus encoding HCV polypeptide NS3.

EXAMPLE 2

Co-administration of HIV immunogens and BLC increases the titer of anti-p55gag

Balb/c mice received bilateral injections into the anterior tibialis muscle of 10 μ g of a p55 plasmid, which encodes HIV gag, either alone or together with a total of 100 μ g of a plasmid encoding B lymphocyte chemokine (BLC; *Nature* 391, 799-803, 1998). Fifty μ g of BLC-encoding plasmid were injected into each muscle.

The animals were bled at 3 and 6 weeks after immunization, and anti-p55gag antibody titer was measured by ELISA. Figure 5 shows that anti-gag antibody titer in

¹ stimulated with a vaccinia virus encoding HCV polypeptide NS3.

² stimulated with a vaccinia virus encoding an unrelated immunogen.

immunized mice is increased at three weeks after immunization and continues to increase up to at least six weeks.

SECRET

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